

S P E C I F I C A T I O N

TITLE

**IMAGE PICKUP APPARATUS AND METHOD,
AND RECORDING MEDIUM**

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BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates, generally, to an image pickup apparatus and method, and a recording medium, and, more particularly, to an image pickup apparatus and method, and a recording medium, suitable for use in picking up an image used in measuring the three-dimensional shape of an object, for example.

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Description of the Prior Art

Methods for determining the three-dimensional shape of an object are broadly divided into active methods and passive methods. The active methods include: a method of determining a distance to an object of measurement by projecting laser light or the like on the object of measurement and then measuring a time required for the reflected light to return; a method of determining the three-dimensional shape of an object of measurement by irradiating the object of measurement with slit pattern light and measuring the shape of the projected pattern on the object of measurement (light cutting method); a method of determining the three-dimensional shape of an object of measurement by irradiating the object of measurement with striped black and white patterns having different periods and using a number of picked up images; and a method of determining the three-dimensional shape of an object of measurement by irradiating the object of measurement with a striped color pattern and using a picked up image (spatial coding method).

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The passive methods typically include a method which is referred to generally as a "stereo method" or a "stereo three-dimensional image measurement." The stereo method picks up an object of measurement via at least two or more cameras disposed at different positions (a base and the other reference cameras), then identifies corresponding pixels between a number of obtained images (base image obtained by the base camera and reference image obtained by the reference camera, a process which is generally referred to as "identification of corresponding points"), and applies the principles of triangulation to positional difference (parallax) between

the pixel on the base image and the pixel on the reference image that are brought into correspondence with each other to thereby determine a distance from the base camera (or the reference camera) to a point on the object of measurement corresponding to the pixels. Thus, when distances to points corresponding to all the pixels

- 5 representing the entire surface of the object of measurement are determined, it is possible to measure shape and depth of the object of measurement.

The identification of corresponding points, which is most important in the stereo method, is performed on the basis of the principle that there are a number of points in real space that are mapped into a point P_a on the base image (points P_1, P_2, P_3 , and the like in real space shown in Fig. 1), and therefore a point P_a' on the reference image corresponding to the point P_a is present on a straight line (referred to as an epipolar line) formed by mapping the points P_1, P_2, P_3 , and the like in real space.

Examples of concrete methods proposed for the identification of corresponding points include: a pixel-based matching method described in "C.Lawrence Zitnick and Jon A.Webb: Multi-baseline Stereo Using Surface Extraction, Technical Report, CMU-CS-96-196, (1996)"; an area-based matching method described in "Okutomi and Kanade: Stereo Matching Using Multiple Baseline Lengths, Transactions of the Institute of Electronics, Information and Communication Engineers D-II, Vol.75-D-II, No.8, pp.1317-1327, (1992)"; and a feature-based matching method described in "H.H.Baker and T.O.Binford: Depth from edge intensity based stereo, In Proc. IJCAI'81, (1981)."

With any of the above-mentioned methods, however, it is difficult to identify corresponding points when the object of measurement, is for example, a wall of a single color or the human face, which has few local features such as shading, shape, and color. Thus, the above methods have a problem of causing a mismatch area.

In order to solve such a problem, a method is proposed in "S.B.Kang, J.A.Webb, C.L.Zitnick and T.Kanade: A Multibaseline Stereo System with Active Illumination and Real-time Image Acquisition, Proc IEEE Int Conf. Comput. Vis., Vol.5, pp.88-93, (1995)," for example. The method irradiates an object of measurement having no local features with light having a periodic pattern, picks up images of the object, and identifies corresponding points on the obtained images.

However, the method of irradiating the object with a periodic pattern can cause an error in identification of corresponding points because of periodicity of the pattern and, therefore, it is not necessarily effective.

- Accordingly, the present applicant has already proposed a method as
- 5 Japanese Patent Application No. Hei 11-344392, for example, (hereinafter referred to as a related application), which includes: irradiating an object of measurement with a non-periodic pattern for image pickup; generating a range image by identifying corresponding points on obtained images; picking up an image of the object of measurement not irradiated with the non-periodic pattern; and pasting an obtained
10 texture image on the range image. The invention described in the related application makes possible identification of corresponding points even when the object of measurement has few local features such as shading, shape, and color.

- However, according to the related application, it is necessary to pick up the object of measurement twice; that is, to pick up the object of measurement being
15 irradiated with the non-periodic pattern and the object of measurement not being irradiated with the non-periodic pattern. Since hand movement or movement of the object of measurement may occur while the object of measurement is picked up twice, it is desirable to make the time required to pick up the object of measurement twice as short as possible.

20 **SUMMARY OF THE INVENTION**

- It is therefore an object of the present invention to provide an image pickup apparatus and method, and recording medium, which shorten as much as possible the time required to pick up the object of measurement twice; that is, to pick up the object of measurement being irradiated with a non-periodic pattern and the object of
25 measurement not being irradiated with the non-periodic pattern.

- In carrying out the present invention and according to a first embodiment thereof, there is provided an image pickup apparatus which includes: a projector for projecting non-periodic pattern light on an object of measurement; a generator for generating image signals of a number of frames by using optical images of the object
30 of measurement; a limiter for limiting input of the optical images of the object of measurement to the generator; and a timing controller for controlling the projector, the limiter, and the generator so that a signal of a pattern image of the object of

measurement being irradiated with the non-periodic pattern light and a signal of a texture image of the object of measurement not being irradiated with the non-periodic pattern light are generated as image signals of consecutive frames; wherein the timing controller allows the projector to project the non-periodic pattern light on the object of measurement for a period of time shorter than an open time within the open time, the open time being a period during which the limiter does not limit input of the optical images of the object of measurement to the generator.

In the above-mentioned image pickup apparatus, the timing controller may control the projector, the limiter, and the generator so that after a signal of a pattern image of the object of measurement being irradiated with the non-periodic pattern light is generated, a signal of a texture image of the object of measurement not being irradiated with the non-periodic pattern light is generated as an image signal of a consecutive frame.

In the above-mentioned image pickup apparatus, the limiter may be a mechanical shutter. When the limiter is a mechanical shutter, the timing controller may control the projector, the limiter, and the generator so that after a signal of a texture image of the object of measurement not being irradiated with the non-periodic pattern light is generated, a signal of a pattern image of the object of measurement being irradiated with the non-periodic pattern light is generated as an image signal of a consecutive frame.

Alternatively, the image pickup apparatus according to the present invention may further include an irradiator for irradiating the object of measurement with flashlight. When the image pickup apparatus further includes the irradiator, and the limiter is a mechanical shutter, the timing controller may control the projector, the limiter, the generator, and the irradiator so that after a signal of a pattern image of the object of measurement being irradiated with the non-periodic pattern light is generated, a signal of a texture image of the object of measurement not being irradiated with the non-periodic pattern light but with flashlight is generated as an image signal of a consecutive frame.

When the image pickup apparatus further includes the irradiator and the limiter is a mechanical shutter, the timing controller may control the projector, the limiter, the generator, and the irradiator so that after a signal of a texture image of the

object of measurement not being irradiated with the non-periodic pattern light but with flashlight is generated, a signal of a pattern image of the object of measurement being irradiated with the non-periodic pattern light is generated as an image signal of a consecutive frame. Alternatively, the generator may generate a number of pattern
5 image signals by using a number of optical images of the object of measurement being irradiated with the non-periodic pattern light, the optical images being simultaneously inputted from a number of different viewpoints.

In carrying out the present invention and according to a second embodiment thereof, there is provided an image pickup method which includes: a projecting step
10 for projecting non-periodic pattern light on an object of measurement; a generating step for generating image signals of a number of frames by using optical images of the object of measurement; a limiting step for limiting input of the optical images of the object of measurement to processing in the generating step; and a timing control step for controlling processing in the projecting step, processing in the limiting step,
15 and the processing in the generating step so that a signal of a pattern image of the object of measurement being irradiated with the non-periodic pattern light and a signal of a texture image of the object of measurement not being irradiated with the non-periodic pattern light are generated as image signals of consecutive frames;
wherein processing in the timing control step allows the processing in the projecting
20 step to project the non-periodic pattern light on the object of measurement for a period of time shorter than an open time within the open time, the open time being a period during which the processing in the limiting step does not limit input of the optical images of the object of measurement to the processing in the generating step.

In carrying out the present invention and according to a third embodiment
25 thereof, there is provided a program on a recording medium, the program including:
a control step for controlling a projector, a limiter, and a generator so that a signal of a pattern image of an object of measurement being irradiated with non-periodic pattern light and a signal of a texture image of the object of measurement not being irradiated with the non-periodic pattern light are generated as image signals of
30 consecutive frames; wherein processing in the control step allows the projector to project the non-periodic pattern light on the object of measurement for a period of time shorter than an open time within the open time, the open time being a period

during which the limiter does not limit input of optical images of the object of measurement to the generator.

The image pickup apparatus, the image pickup method and the program on a recording medium according to the present invention project non-periodic pattern light on an object of measurement, generate image signals of a number of frames by using optical images of the object of measurement, and limit input of the optical images of the object of measurement to the generating processing. In addition, the image pickup apparatus, the image pickup method and the program on a recording medium control the projecting processing, the limiting processing, and the generating processing so that a signal of a pattern image of the object of measurement being irradiated with the non-periodic pattern light and a signal of a texture image of the object of measurement not being irradiated with the non-periodic pattern light are generated as image signals of consecutive frames. Further, the image pickup apparatus, the image pickup method and the program on a recording medium effect control so that the non-periodic pattern light is projected on the object of measurement for a period of time shorter than an open time within the open time, the open time being a period during which input of the optical images of the object of measurement to the generating processing is not limited.

The above and other objects, features and advantages of the present invention and the manner of realizing them will become more apparent, and the present invention itself will best be understood from a study of the following description and appended claims with reference to the attached drawings showing some preferred embodiments of the present invention.

DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram to assist in the explanation of an epipolar line;
Fig. 2 is an external front view of a three-dimensional camera to which the present invention is applied;
Fig. 3 is an external rear view of the three-dimensional camera;
Fig. 4 is a block diagram showing an electrical configuration of the three-dimensional camera;
Fig. 5 is a block diagram showing a configuration example of a pattern projecting unit;

Fig. 6 is a block diagram showing a configuration example of an image pickup unit;

Fig. 7 is a block diagram showing another configuration example of an image pickup unit; and

5 Figs. 8-12 are diagrams to assist in the explanation of timing of picking up a stereo image and a texture image.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A three-dimensional camera (3D camera) to which the present invention is applied will be described with reference to Figs. 2 to 4. In response to shutter release 10 by the user, the three-dimensional camera consecutively picks up two pattern images (stereo images) of an object of measurement irradiated with pattern light and a texture image of the object of measurement not irradiated with pattern light, and then supplies the picked up stereo images and the texture image picked up consecutively after the pickup of the stereo images to a personal computer or the like.

15 Fig. 2 is an external front view of the three-dimensional camera. Fig. 3 is an external rear view of the three-dimensional camera.

Provided on the front side (the side facing an object of measurement) of the three-dimensional camera are image pickup units 1 and 2 that each include a lens group 31, a CCD (Charge Coupled Device) 32, and the like (described later in detail 20 with reference to Figs. 6 and 7) and thereby convert an optical image of an object of measurement into an electric image signal, the image pickup units 1 and 2 being disposed at a given distance from each other.

Provided on the top of the three-dimensional camera are an image capturing button 3 actuated in timing in which the user issues a command for image pickup, 25 and a pattern projecting unit and strobe light 4 that irradiates an object of measurement with pattern light or flashlight (not pattern light).

An interface 5 is provided on a side of the three-dimensional camera. Examples of the interface 5 include RS-232C, IEEE1394, USB, Ethernet and other wired interfaces and wireless interfaces that send and receive infrared signals, radio 30 signals and the like. The interface 5 transmits data of the stereo images and the texture image to a personal computer.

Provided on the rear side (the side facing the user) of the three-dimensional camera are a display 6 for displaying a picked-up image or the like, and operation buttons 7 operated when various settings are inputted.

Fig. 4 shows an electrical configuration of the three-dimensional camera. An 5 operation unit 11 detects operation by the user of the image capturing button 3 and the operation buttons 7, and then outputs information on the user operation to a timing control unit 12 or a display control unit 17. The timing control unit 12 controls timing of light emission of a strobe light 13 and a pattern projecting unit 14 and shutter timing of the image pickup units 1 and 2 (described later in detail) 10 according to a control program recorded on a recording medium 18 and the user operation information inputted from the operation unit 11. The timing control unit 12 also controls timing of image capturing by an image capturing unit 15 according to the user operation information inputted from the operation unit 11.

The strobe light 13 is used as required when picking up a texture image of an 15 object of measurement, and irradiates the object of measurement with flashlight under control of the timing control unit 12.

The pattern projecting unit 14 is used when picking up stereo images, which are used to obtain a range image of the object of measurement, and projects pattern light on the object of measurement under control of the timing control unit 12.

Fig. 5 shows a configuration example of the pattern projecting unit 14. The 20 pattern projecting unit 14 includes a light source 21 formed by a xenon tube, an LED or the like, a condenser lens 22, a slide 23 on which a non-periodic pattern produced by using uniform random numbers or normal random numbers is printed, and a projection lens 24.

Light generated in the light source 21 of the pattern projecting unit 14 is 25 passed through the slide 23 and condensed on the projection lens 24 by the condenser lens 22, and then projected on a surface of the object of measurement by the projection lens 24. The light source 21 emits light for a time shorter than shutter time of the image pickup units 1 and 2 (described later) within the shutter time.

Under control of the timing control unit 12, the image capturing unit 15 30 captures image signals inputted from the image pickup units 1 and 2 (stereo image and texture image signals) into its built-in frame memory, and thereafter outputs the

image signals to a data storage unit 16. The data storage unit 16 stores the image signals inputted from the image capturing unit 15. The display control unit 17 reads the image signals from the data storage unit 16 for display on the display 6 according to the user operation information inputted from the operation unit 11.

5 The recording medium 18, on which a program is recorded, is formed by a removable medium such as a magnetic disk (including a floppy disk), an optical disk (including CD-ROM (Compact Disc-Read Only Memory) and DVD (Digital Versatile Disc)), a magneto-optical disk (including MD (Mini Disc)), or a semiconductor memory, or formed by a ROM, a hard disk or the like incorporated in
10 the three-dimensional camera.

Next, Fig. 6 shows a configuration example of the image pickup unit 1. The lens group 31 of the image pickup unit 1 condenses an optical image of the object of measurement on a CCD 32. The CCD 32 in normal operation stores a charge resulting from photoelectric conversion according to the amount of light received for
15 a specified time Tf, and then outputs the stored charge as an image signal for one frame to the image capturing unit 15. The CCD 32 has a built-in electronic shutter function, which allows the CCD 32 to store charge for a shutter time Ts, which is a latter part of the storage time Tf for storing a charge for one frame and to discard a charge stored during a first part of the storage time Tf ($Tf - Ts$).
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As shown in Fig. 7, the image pickup unit 1 may be provided with a mechanical shutter 41 between the lens group 31 and the CCD 32. The mechanical shutter 41 may transmit light from the lens group 31 in timing controlled by the timing control unit 12. The mechanical shutter 41 provided in the image pickup unit 1 allows the CCD 32 to be exposed to light in any given timing. A configuration of
25 the image pickup unit 2 is the same as that of the image pickup unit 1, and therefore its description will be omitted.

Description will next be made of timing in which the three-dimensional camera consecutively picks up an image of the object of measurement irradiated with pattern light and an image of the object of measurement not irradiated with pattern
30 light in response to depression of the image capturing button 3 by the user.

In obtaining a stereo image by picking up an image of the object of measurement being irradiated with pattern light, the timing control unit 12 operates

the image pickup units 1 and 2 in synchronism with each other so that the CCD 32 stores charge only for the shutter time T_s using the electronic shutter function of the CCD 32 or the mechanical shutter 41, and also applies the pattern light for a time shorter than the shutter time T_s within the shutter time T_s . In this case, when the
5 shutter time T_s is shortened, it is possible to shut out most of ambient light. In addition, by applying the pattern light only for a time shorter than the shutter time T_s within the shutter time T_s , it is possible for the CCD 32 to obtain a steady amount of light only from the pattern light. Thus, it is possible to reliably pick up a stereo image of the object of measurement being irradiated with the pattern light at all times
10 without being affected by intensity of ambient light around the object of measurement.

In obtaining a texture image by picking up an image of the object of measurement not being irradiated with pattern light, the timing control unit 12 operates either one of the image pickup units 1 and 2, and it is necessary to determine
15 whether or not to use a shutter (the electronic shutter function of the CCD 32 or the mechanical shutter 41) and when the shutter is used, appropriately change shutter time according to the intensity of ambient light and the like.

Consideration will now be given to a case where the image pickup units 1 and 2 do not have the mechanical shutter 41 (case of Fig. 6). In this case, when a texture
20 image of the object of measurement not being irradiated with pattern light and a stereo image of the object of measurement being irradiated with pattern light are picked up in that order, the longest possible image pickup time (time for which the three-dimensional camera needs to be held without hand movement) is twice the time T_f for storing a charge for one frame ($2T_f$), as shown in Fig. 8.

25 As shown in Fig. 9, on the other hand, when a stereo image of the object of measurement being irradiated with pattern light and a texture image of the object of measurement not being irradiated with pattern light are picked up in that order, the longest possible image pickup time is the shutter time T_s for picking up the stereo image added to the time T_f for storing a charge for one frame of the texture image
30 ($T_s + T_f$). Since the shutter time T_s is shorter than the time T_f for storing a charge for one frame, the image pickup time when the images are taken in the order shown

in Fig. 9 is shorter than that when the images are taken in the order shown in Fig. 8, thereby preventing hand movement from affecting the images.

Consideration will next be given to a case where the image pickup units 1 and 2 have the mechanical shutter 41 (case of Fig. 7). In this case, as described above, the image pickup units 1 and 2 can each store a charge in the CCD 32 in any given timing (for example, in a first part T_s of the storage time T_f for storing a charge for one frame). Therefore, as shown in Fig. 10, even when a texture image of the object of measurement not being irradiated with pattern light and a stereo image of the object of measurement being irradiated with pattern light are picked up in that order, the longest possible image pickup time is the time T_f for storing a charge for one frame of the texture image added to the shutter time T_s for picking up the stereo image ($T_s + T_f$). Thus, the image pickup time when the images are taken in the order shown in Fig. 10 is also shorter than that when the images are taken in the order shown in Fig. 8, thereby preventing hand movement from affecting the images.

As shown in Fig. 11, when the mechanical shutter 41 is used also in taking a texture image of the object of measurement not being irradiated with pattern light, the image pickup time is a shutter time (charge time of the CCD 32) T_c for taking the texture image of the object of measurement not being irradiated with pattern light added to the shutter time T_s for picking up a stereo image of the object of measurement being irradiated with pattern light ($T_c + T_s$). Since the shutter time T_c is shorter than the time T_f for storing a charge for one frame, the image pickup time when the images are taken in the order shown in Fig. 11 is even shorter than that when the images are taken in the order shown in Fig. 10, thereby preventing hand movement from affecting the images. If the use of the mechanical shutter 41 in taking a texture image of the object of measurement not being irradiated with pattern light renders the time for storing a charge in the CCD 32 insufficient, the strobe light 13 may be emitted during the shutter time T_c .

In a case where the image pickup units 1 and 2 have the mechanical shutter 41 (case of Fig. 7), when the mechanical shutter 41 is used also in taking a texture image of the object of measurement not being irradiated with pattern light, the texture image of the object of measurement not being irradiated with pattern light and a stereo image of the object of measurement being irradiated with pattern light

may be picked up in that order, as shown in Fig. 12. The image pickup time in this case is the same ($T_c + T_s$) as when the images are taken in the order shown in Fig. 11, and therefore is even shorter than that when the images are taken in the order shown in Fig. 10, thereby preventing hand movement from affecting the images.

5 Image signals of the stereo images and the texture image picked up by the image pickup units 1 and 2 in the timing described above are recorded in the built-in frame memory of the image capturing unit 15, thereafter stored in the data storage unit 16, and then supplied from the interface 5 to a personal computer or the like.

10 The personal computer or the like, not shown, sets one of the stereo images as a base image and the other as a reference image for identification of corresponding points, generates a range image on the basis of the result of identification, and pastes the texture image on the range image to thereby generate an image showing three-dimensional shape of the object of measurement.

15 It is to be noted that images generated by the three-dimensional camera according to the present invention may be applied not only to the stereo method but also to other methods of obtaining a three-dimensional shape of an object.

20 As described above, the image pickup apparatus, the image pickup method and a program on a recording medium according to the present invention control the timing of projecting pattern light, input of optical images of the object of measurement, and the image signal generating process, and thereby generate a signal of a pattern image of the object of measurement being irradiated with non-periodic pattern light and a signal of a texture image of the object of measurement not being irradiated with non-periodic pattern light as image signals of consecutive frames. Thus, it is possible to reduce the time required to pick up the object of measurement twice.

25 Although the present invention has been described with reference to specific embodiments, those of skill in the art will recognize that changes may be made thereto without departing from the spirit and scope of the invention as set forth in the hereafter appended claims.